



Nuclear data Exercises

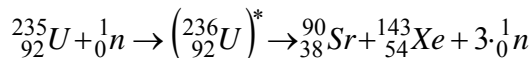
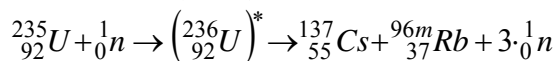
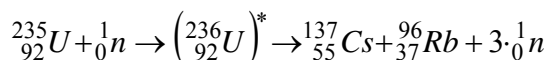
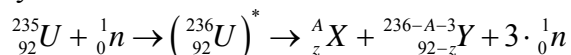
1. What is the total energy released (Q-value) in the spontaneous transformation of Po-210 to Pb-206 by alpha emission?
5.40745 MeV
2. What is the a) average, and b) maximum alpha particle energy for the spontaneous transformation of Pu-239?
a) α mean energy = 5.238 MeV
b) α max energy = 5.2445 MeV
3. What is the maximum kinetic energy of the betas released in the spontaneous transformation of Sr-89 to Y-89?
1.4951 MeV
4. What is the average beta kinetic energy? Note that the average kinetic energy is approximately 1/3 of the maximum value.
584 keV
5. 4. The decay of Fe-55 by electron capture to Mn-55 can be written $\text{Fe-55} \rightarrow \text{Mn-55}^* + \nu$ in which an inner shell electron in Fe-55 is captured by the nucleus and combines with a proton (i.e. $e + p \rightarrow n + \nu$) in the nucleus to form a neutron and a neutrino ν . The process of electron capture leaves a vacancy in an electron shell that is then filled immediately by electrons from higher levels cascading down. The process is characterised by the emission of xrays and associated Auger electrons.
 - a). What is the total decay energy (Q-value) for this reaction?
0.23138 MeV
 - b) What is the energy of the mono-energetic neutrino created in this reaction?
 $231.4 - 4.0 - 1.7 = 225.7 \text{ keV}$
 - c). What percentage of the total decay energy is carried away by the neutrino?
 $225.7 / 231.4 * 100 = 97.5\%$
 - d). What is the isotopic (heat) power of Fe-55?
79.8 mW/g
 - e). What is the total power (per gram) emitted?
 $79.8\text{e-}3 / 2.5 * 97.5 = 3.16 \text{ W/g}$
6. Nuclear reactor power is driven by the nuclear fission of U-235 with thermal neutrons ($E = 0.025 \text{ eV} = 2.2 \text{ km/s}$).
 - a. How much is fission predominant compared to neutron capture – (n, γ) reaction- and scattering?
 $583.2 / (15.11 + 98.95) = 5.11 \text{ times}$



- b. Find the two main fission products from the thermal fission of U-235 with half-lives within 25-35 years.

55Cs-137 and 38Sr-90

- c. Assuming an average 3 neutrons emission by fission determine for the two fission products found in 6.b. the other fission products produced during the binary fission.



Rb96, Rb96m, Xe143

- d. What's the amount of the 4 fission products produced per 1 tone of U-235?

Number of U-235 nuclides: $N_U = N_A / A_U \cdot M_U$

Amount produced: $M_X = N_U \cdot Y_{\text{CumulX}} / N_A \cdot A_X$

$M_X = Y_{\text{CumulX}} \cdot A_X / A_U \cdot M_U$

$$6.22\text{e-}2 \cdot 136.907 / 235.044 = 36.2 \text{ kg Cs-137}$$

$$5.73\text{e-}2 \cdot 89.908 / 235.044 = 21.9 \text{ kg Sr-90}$$

$$1.76\text{e-}3 \cdot 95.934 / 235.044 = 0.72 \text{ kg Rb-96}$$

$$6.75\text{e-}4 \cdot 95.934 / 235.044 = 0.28 \text{ kg Rb-96m}$$

$$7.89\text{e-}4 \cdot 142.935 / 235.044 = 0.48 \text{ kg Xe-143}$$

- e. What's the decays heat produced by the two fission products found in 6.b.?

$$\text{Cs-137 decays heat: } 9.67 \text{ W/g} \cdot 36.2 \text{ kg} = 350 \text{ kW}$$

$$\text{Sr-90 decays heat: } 0.142 \text{ W/g} \cdot 21.9 \text{ kg} = 3.11 \text{ kW}$$

- f. What amounts of U-235 shall be fissioned in order to produce the annual limits of toxicity (inhalation and ingestion) for the two fission products found in 6.b.?

$$ALI_{\text{inh}} \text{ of Cs-137} = 5.13\text{e}5 \text{ Bq} = 1.595\text{e-}7\text{g} \rightarrow 1.595\text{e-}7\text{g}/36.2 \text{ kg/t} = 4.42 \mu\text{g U-235}$$

$$ALI_{\text{ing}} \text{ of Cs-137} = 1.54\text{e}6 \text{ Bq} = 4.79\text{e-}7\text{g} \rightarrow 4.79\text{e-}7\text{g}/36.2 \text{ kg/t} = 13.2 \mu\text{g U-235}$$

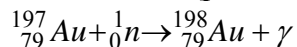
$$ALI_{\text{inh}} \text{ of Sr-90} = 1.25\text{e}5 \text{ Bq} = 2.45\text{e-}8\text{g} \rightarrow 2.45\text{e-}8\text{g}/21.9 \text{ kg/t} = 1.12 \mu\text{g U-235}$$

$$ALI_{\text{ing}} \text{ of Sr-90} = 7.14\text{e}5 \text{ Bq} = 1.40\text{e-}7\text{g} \rightarrow 1.40\text{e-}7\text{g}/21.9 \text{ kg/t} = 6.40 \mu\text{g U-235}$$

7. The fast neutron activation was found to be an efficient, quick and accurate method of characterizing the precious metal objects routinely in bulk, with a large sample throughput. In this exercise the researcher is interested to analyze gold jewelry using neutron activation.



- a. Describe the reaction (parent/daughters of the reaction)



- b. Looking at the cross-section, which neutron spectrum is more favorable for the activation?

Epi thermal neutron: 1562 barn (resonance integral)

- c. The researcher is interested in prompt gamma emission. Which lines will he measure?

214.971 keV, 247.573 keV, 262.404 keV (...734 lines)

- d. If he were doing delayed gamma spectroscopy, which lines would he measure?

411.802 keV, 675.884 keV, 1087.68 keV (from Au-198)

- e. The researcher is actually irradiating a 2 g gold sample (18 carats i.e. 75% gold content) with a 14 MeV neutron flux of $4 \cdot 10^7 \text{ n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ during 1 min. How much activated gold (atoms and grams) did he produced at the end of the irradiation? What does that activated gold becomes after 27 days?

$$N_{\text{Au-198}} = \Phi * t * \sigma * N_A * M_{\text{Au-197}} / A_{\text{Au-197}}$$

$$N_{\text{Au-198}} = 4\text{e}7 * 60 * 1\text{e-}3 * 1\text{e-}24 * 6.023\text{e}23 * 1.5 / 196.967$$

$$N_{\text{Au-198}} = 11000 \text{ Au-198 atoms}$$

$$M_{\text{Au-198}} = N_{\text{Au-198}} * A_{\text{Au-198}} / N_A$$

$$M_{\text{Au-198}} = \Phi * t * \sigma * M_{\text{Au-197}} * A_{\text{Au-198}} / A_{\text{Au-197}}$$

$$M_{\text{Au-198}} = 4\text{e}7 * 60 * 1\text{e-}3 * 1\text{e-}24 * 1.5 * 197.968 / 196.967$$

$$= 3.62\text{e-}18 \text{ g Au-198}$$

After 27 days (10 half lives) Au-198 is fully decayed into stable Hg198